MODERN CONCEPTS OF CARDIOVASCULAR DISEASE

Spatial Vectorcardiography (I)*‡

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Vectorcardiography is a method of registering the electrical activity of the heart. Unlike the conventional electrocardiogram, which is a scalar representation of electrical activity, the vectorcardiogram is a spatial representation of the electromotive field forces, generated during cardiac activity, as projected in three separate planes: the horizontal (H), frontal (F), and sagittal (S). At any instant during ventricular depolarization, a dipole† exists which is the algebraic sum, or resultant, of all individual or elementary dipoles generated at that moment. With vector presentation, an arrow is employed as a geometrical symbol to indicate the resultant field force effective at the instant of observation, the instantaneous vector. Its length indicates the magnitude, orientation, and direction of the field; the arrow tip points to the positive side (follow-ing Einthoven's convention) to indicate polarity. The vector loop (QRS loop), therefore, represents the course of all instantaneous vectors during depolarization. A separate loop is obtained during ventricular repolarization (T loop).

The vector concept underlying spatial vectorcardiography assumes that the generation of electromotive forces by all segments of the active heart contributes to one electromotive field. All electrocardiographic leads, irrespective of the technique employed, merely tap this field through projection upon lead lines, the angle of which is determined by the respective points at which they are connected to the galvanometers. Thus, it can be readily seen that the vector concept is unitarian, viewing and treating all electrocardiographic curves obtained as derivatives of the electromotive field, as presented by the spatial cardiac vector. Exploration for local potentials§ in clinical practice is considered not possible. Although the concept of local potential with inherent assignment of local shape specificity to the curves is no longer considered valid, the enormous quantity of clinical material with autopsy correlation lends itself to interpretation, in spite of changing concepts.

VALIDITY OF THE DIPOLE AND VECTOR CONCEPT

The dipole theory, the basis of vector con-

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†A dipole may be defined as the combination of two electrical sources of equal, but opposite, charges when surrounded by a conducting medium, such as body fluids.

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§Local potentials were thought to be recorded by means of exploring electrocardiography, based on the application of the unipolar recording technique. It was hoped that the electrical potential, generated by the muscle area subjacent to the electrode, could be recorded without any, or appreciable, interference from potentials generated by more remote areas.
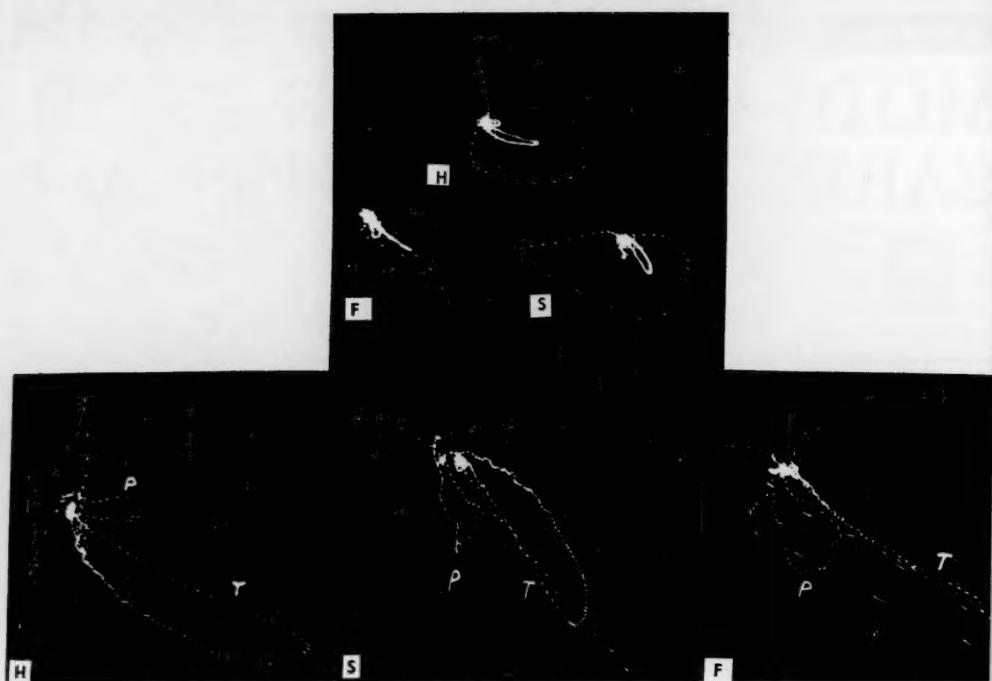
Figure 1A. *Normal vectorcardiogram. The lower section is recorded at higher amplification.*
(H) Horizontal plane projection; (S) sagittal plane projection; (F) frontal plane projection.

cept and vectorcardiography, is regarded as adequate at the present time for the handling of the cardiac electrical events known. The ideal physical situation requires a point source of electricity within a symmetrically shaped thorax of homogeneous conductivity. There are limitations to the exactitude applicable to biological problems. An approach of exaggerated exactness encompassing all, even the most minute factors, might prove a pitfall by depriving us of concepts useful to the problem on hand, only because of their lack of complete theoretical validity. Duchosal et al.[1] showed that unipolar leads, recorded along the axis of diametrically opposed parts of the body, gave electrocardiograms which were, in configuration and timing, mirror images of each other. Their original observation was extended in a series of studies by Schmitt et al.[2, 3] Excellent cancellations were found in normal subjects and most patients studied. Infrequent poor cancellations were viewed as largely the result of technical limitations, and not due to the interference of local patterns. Furthermore, it has been possible to go beyond the mere ability to derive scalar electrocardiograms

from the spatial vectorcardiogram with reasonable accuracy. Direct electronic reconstruction of any surface lead, precordial or other, has been achieved with a very high degree of accuracy as to shape and phase of the complexes through feeding so-called vector component leads into the electronic gear.[4, 5] It should be emphasized here that the leads employed were placed as distal to the heart as physically possible, allowing for reconstruction of the most minute detail. The conclusion may be permissible that "local" potentials do not have to be of detectable significance, and that handling of the electromotive field, generated by the heart on the basis of the vector concept, is of sufficient accuracy, allowing for our present state of knowledge.

PURPOSE OF VECTORCARDIOGRAPHY

The vectorcardiographic curves present graphically the phase relationship of voltages from electrocardiographic leads of known geometrical relationship to each other. Although contained in the vector component leads, their electrocardiographic analysis (duration, shape,
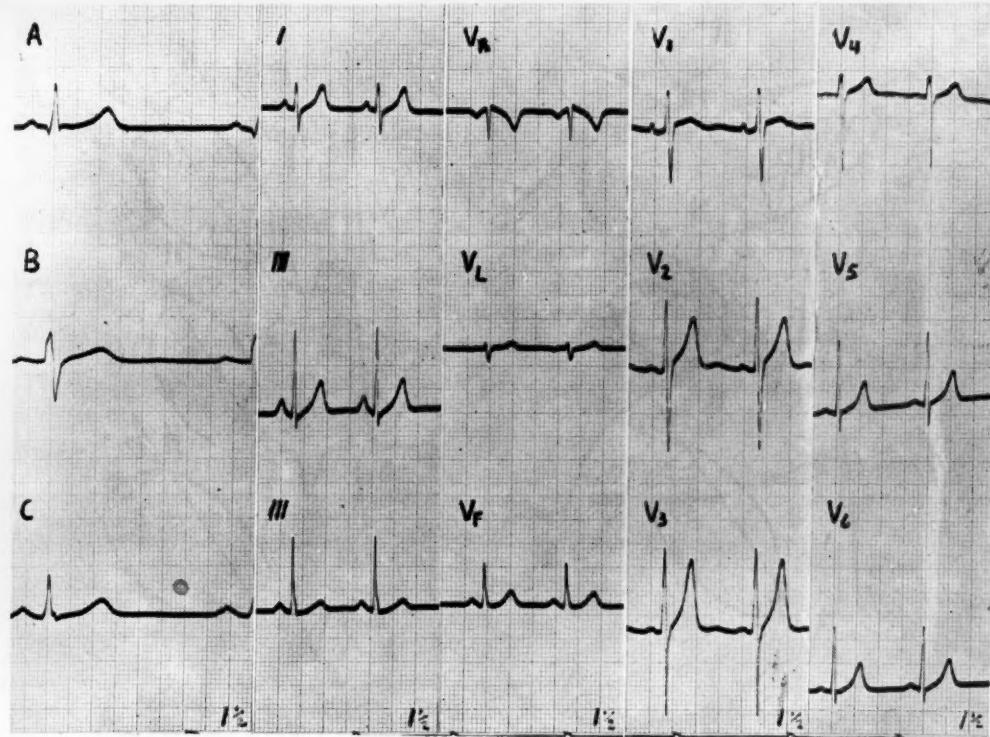
Figure 1B. *A, B, and C are the orthogonal vector component leads from which the vector loops are synthesized with the aid of a cathode-ray oscilloscope. Their fusion to vector curves gives a graphic presentation of their phase relationship.*

voltage, slope, and time-relationship of main deflections) gives the same information in many, but not all, situations.

Properly selected, simultaneously recorded, unipolar chest leads (with Wilson's central terminal) often allow an estimation of phase relationship along a plane approximately horizontal. Vector plotting has certain limitations, particularly when time intervals of 0.01 second become significant, or polyphasic complexes are encountered.

Present-day electrocardiography, in the hands of the experienced clinician, is recognized as a diagnostic tool of great accuracy. There is also no question as to the desirability of narrowing the gap of equivocal, confusing, or erroneously negative information given. The phase relationship, as computed through the cathode-ray oscilloscope and presented as a vector curve, has added new diagnostic or differential information not obtainable from the conventional electrocardiogram.

Vectorcardiography, beyond its direct diagnostic value, has provided a tool to teach electrocardiography through a unitarian concept, admitting deductive analytic processes in a field where memorization of empirically collected patterns was mostly required. Furthermore, the presentation of the vector concept, through the controversy it created, has stimulated new interest, work, and discussion about the foundations of "electrocardiology."

SPREAD OF THE EXCITATION WAVE

The sequence of excitation of the ventricular musculature and the generation of electromotive forces (EMF), which follows the excitation, are determined by the anatomy of the bundle of His and the Purkinje fibers.

The study of galvanometric deflections from leads, at or near the heart, can yield only general information as to the order of the spread of the excitation wave, since these are merely

recording points in the field of the resultant dipole.[6] Present knowledge of the physical properties of the lead systems most commonly employed in such experiments in the past obliges one to concur with Fahr's statement that the information is general, and devoid of the exactitude implied.[6] The curves obtained "tapped the spatial cardiac vector," i.e., the resultant of all forces generated, not predominantly the electrical events of the muscle area subjacent to the exploring electrode. The limitations of the techniques employed were apparent to Lewis, Meakins, and White,[7] becoming, however, less emphasized in subsequent years. The experiments and publications of Harris,[8] and somewhat later of Schaefer,[9] based on "micro" bipolar systems with the two electrode points as close to each other as possible, had drawn attention to the assumption that exact knowledge as to the spread of the excitation wave was available from experiments with semidirect or unipolar electrode systems. Studies of Durrer, Scher, and Sodi-Pallares,

have begun to re-establish the foundations of knowledge about the sequence of excitation.

Although much has been learned about the normal spread pathways, the effects of chronic overload, dilatation, changes of intramural and intraventricular pressures, localized damage and conduction defects remain to be studied. As Sodi-Pallares repeatedly has pointed out, this knowledge is fundamental. Through the understanding of the normal pathways and their alterations in pathological states, the genesis of cardiac chamber preponderance, systolic and diastolic overload, and their relation to intraventricular conduction, may become clarified. This remains to be done.

SPATIAL VECTORCARDIOGRAM

The representation of the vectorcardiogram of ventricular activation consists of a point of origin (white center) with a rapidly inscribed large loop, the QRS loop, followed by a much more slowly inscribed smaller loop, the T loop, which originates from the point of return
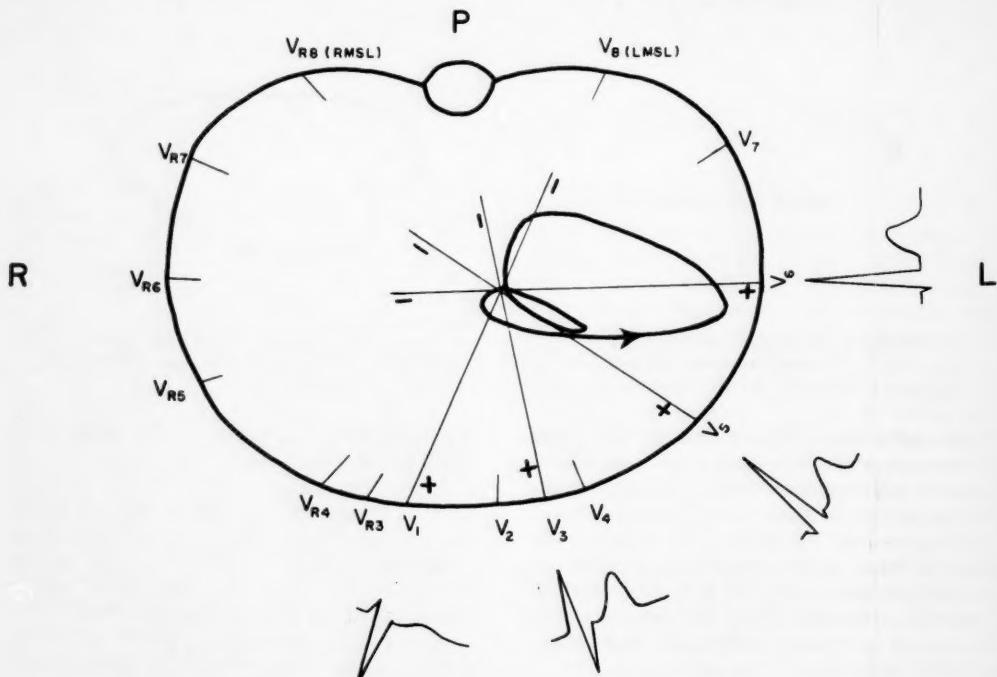

Figure 2. *Schematic representation of the cross-section of the chest, as viewed from above. The precordial unipolar leads are related to the horizontal plane projection of the spatial vectorcardiogram. The configuration of V_1 and V_6 does not reflect the right ventricular or left ventricular potential, respectively, but the projection of the composite electromotive field forces. (RMSL) right mid-scapular line; (LMSL) left mid-scapular line.*

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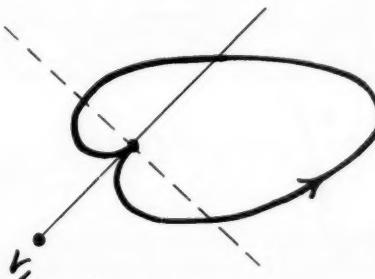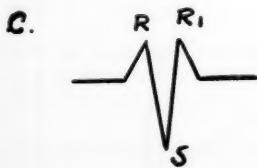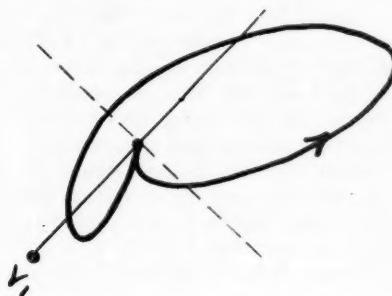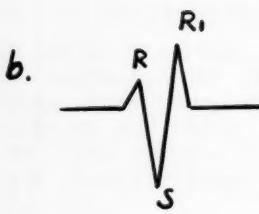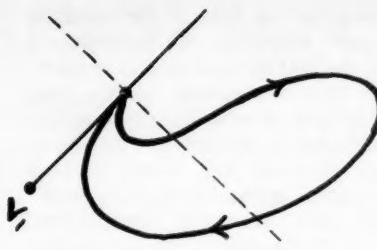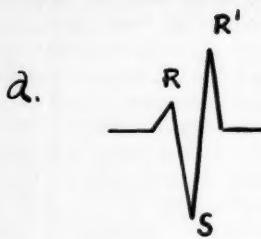
Figure 3. *Horizontal vector projections (H), related to precordial lead V_1. RSR' configurations can result from the projection of distinctly different situations: (a) right ventricular preponderance; (b) right bundle-branch block; (c) normal variations.*

of the QRS loop (fig. 1A and B). Since the vectorcardiogram is recorded on a stationary film, the white center of the graph corresponds to the isoelectric line of the normal electrocardiogram, i.e., the fixed point at which the electron beam of the cathode-ray oscilloscope is photographed during the P-R, S-T, and T-P intervals. Normally, the QRS and T loops are almost completely closed; i.e., their points of origin and return are essentially identical.

The rate and speed of inscription can be determined by comparing the distance between the interrupted segments of the vector loop. Care should be taken to corroborate alteration of the speed from two planes, since transient, initial, or terminal slowing may be due to a perpendicular relationship of the vector loop to the plane of projection.

From the spatial cardiac vector, as projected to three selected planes, one can derive any of the configurations of the routine scalar electrocardiograms, unipolar as well as bipolar (fig. 2). The justification for it, and its limitations, have been already discussed.

The graphic presentation of the phase relationship has been particularly useful in differentiating normal from abnormal electrocardiograms in infants. In infants older than two months, the direction of inscription of the horizontal vector loop is the same as that in adults, but the orientation is somewhat more anterior.[10] Furthermore, with RSR' configura-

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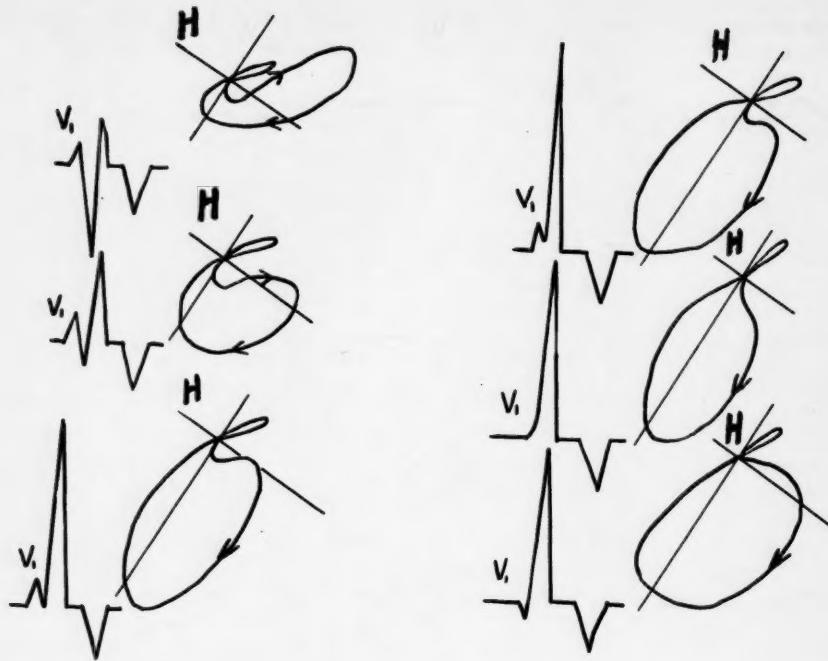
Figure 4. *The various configurations of right-sided chest leads, encountered in right ventricular preponderance, are intimately related, differing mostly in the degree of deviation of the clockwise inscribed vector loop anteriorly, and to the right.*

tions in right-sided chest leads (fig. 3), conduction defects, normal variants and right ventricular preponderance (fig. 4) can easily be separated by vectorcardiograms.[11] Biventricular hypertrophy (fig. 5) can be indentified vectorcardiographically,[12] and in A-V cushion defects (fig. 6) the superior orientation of the vector is the most important diagnostic clue.[13] Anteroseptal, localized anterior, diaphragmatic, and lateral myocardial infarctions, are clearly indicated on the vectorcardiogram. Before vectorcardiography was introduced, infarctions of the posterolateral and posterior walls usually escaped identification (fig. 7). Since then it has been accepted that a posterior infarction will result in anterior displacement of the vector loop and in high R waves in V_1, V_2, and V_3 (fig. 8).[14]

VECTOR RECORDING TECHNIQUES

An extension of the Einthoven triangle to an equilateral tetrahedron was used by Burch and his associates as the geometrical structure for electrode placement.[15] In their studies, the authors have used throughout a cube arrangement of electrode placement (fig. 9), based on a modification of the orthogonal technique of Duchosal and Sulzer.[1] The use of correcting average network electrode systems has been advocated. Their application is complex, time-consuming and not indicated at the present state of knowledge of vectorcardiography, of which the recording of phase relationship is its greatest value beyond scalar electrocardiography. Records obtained with correcting systems and cube technique, incidentally, are similar in all main aspects.

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